SULFUR HEXAFLUORIDE REPROCESSING SYSTEM DESIGN FOR A LARGE PULSED POWER ACCELERATOR

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INTRODUCTION

The Particle Beam Fusion Accelerator-II (PBFA-II) is a large, high power accelerator being constructed at Sandia National Labs to conduct research in inertial confinement fusion. One key to the success of this machine is the ability to produce an electrical pulse at the target with a well defined shape (power versus time). This requires that the 36 electrical drivers be initiated with good simultaniety. Simultaniety (or jitter) of the 36 module shot outputs is controlled by a sequence of pulse outputs starting at the control/monitor input to the trigger amplifier and then to the Marx trigger generators, the Marx generators, and finally the rimfire switches. A homogeneous insulating vapor in these switches is thought to reduce the jitter; however, actual data are not available to establish this concept. PBFA-II uses sulfur hexafluoride (SF6) for this insulating vapor.

In the past at Sandia National Labs, a commercial SF6 reclaimer unit has been used to reprocess vapor. These reclaimers are well designed for their primary purpose--the reprocessing of substation transformer and circuit breaker vapor for the electrical generation industry. They are not designed to meet the more exacting needs of a research accelerator such as PBFA-II. An SF6 reprocessing system was designed for use in PBFA-II to overcome the deficiencies found in commercial reclaimers.

This paper describes the requirements placed on an SF6 reprocessing system when operating in a fusion research accelerator, resulting in criteria used to design the reprocessing system, and the subsequent design implemented to meet these criteria.

Sulfur Hexafluoride Properties and Contamination

SF6 is a very heavy vapor and calculations based on perfect gas assumptions cannot generally be used. Figure 1 presents a pressure-enthalpy diagram for SF6 and is basic to understanding the reprocessing system operation. As long as the vapor is very pure and dry, it is an excellent electrical insulator in the spark gap switches in PBFA-II. The operating environment of the machine, however, introduces various types of contamination. These are discussed below.

Vapor Contamination

The SF6 becomes ionized by the electrical current flow when the spark gap switches are initiated and when the laser trigger system initiates the main gas switches in the pulse forming lines of the accelerator. Recombination following ionization leads to many stable compounds; however, the major reaction is to reform SF6. Other sulfur-fluorine compounds form such as SF_2, SF_4, and S_2F_{10}. Metal vapors from the electrodes react forming stable metal fluorides which exist in solid form and are fine powders. Some evidence of fluoride compounds forming from chamber wall materials has been detected. When water vapor is present, HF is formed as well as acid forms of the various sulfur-fluorine compounds.

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With the exception of SF6, most other sulfur-fluorine compounds generated are toxic. HF is highly corrosive and will cause serious problems in the optical system components which are in direct contact with the SF6 vapor stream. Sintered metal fluoride powders have caused shorting across electrode gaps. Experience has shown that accelerator performance is degraded by the presence of these contaminants.

Introduction of Water and Oil

All of the switches associated with the Marx generators in PBFA-II are located in transformer oil. The rimfire switches are located in the deionized water section. These switches are constructed of acrylic insulators sealed by elastomer O-rings. SF6 vapor is fed to and removed from the switches by polyethylene tubing. All three of these materials exhibit finite water and oil diffusion coefficients. This can cause a variety of nondesirable conditions in the switches. Water vapor will continuously diffuse through the switch chamber until the pressurized SF6 vapor reaches its moisture saturation level of 900 ppm (wt.) at 50 psia and 70° F. Commercial grade SF6 is specified to meet a moisture level of 1% of this value, or 9 ppm (wt.), but routinely is as low as 4-5 ppm (wt.). There is past evidence that oil can diffuse through plastic and elastomer switch and vapor feed line construction materials. Gross leakage is always possible in the switch seals and mechanically failed components will lead to large bulk input of the fluids.

Introduction of oil and water into the switches can cause serious problems on switch operation. Periodic cleaning of the switches has resulted in restoring switches to normal operation, but frequent cleaning is a very expensive and time consuming operation. Adequate reprocessing of the vapor to remove these contaminants may lead to extended periods between switch rebuilds and will save associated costs and time.

Criteria for PBFA-II SF6 Reprocessing System

A number of criteria were identified which the design of the SF6 reprocessing system must meet. These are briefly discussed here.

Contaminant Removal

The primary purpose of the reprocessor is to produce clean, dry vapor for the spark gap switches in PBFA-II. One criterion was that the reprocessor perform better than a commercial reclaimer; better was defined to be the removal of contaminants and the production of vapor with specifications near or equal to commercial cylinder vapor. Table I is a listing of the detailed specifications for the SF6 vapor produced.

Purge Rate and Mass Throughput

Two purge rates were specified for the machine. Since there is always a possibility that the machine will prefire, it was desirable to purge all switches before attempting to fire the accelerator again. Turnaround time was a very important consideration and the requirement to complete this fast purge in 12 minutes was established. A purge is defined as four mass

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Table I

SF6 PROPERTIES AND SPECIFICATIONS

Physical Properties

Molecular Weight	146.06
Critical Density	45.6 Lb/Ft3
Critical Pressure	545 psia
Critical Temperature	114.2°F
Approx. Specific Gravity	5.1
Water Solubility in Liquid Phase	350 ppm (wt)

Specifications

Component	ASTM D2472 Specifications (Wt. %)	Manufacturer's Specifications (Wt. %)
Sulfur Hexafluoride	99.8	99.8
Air	0.05	0.05
Carbon Tetrafluoride	0.05	0.021
Hydrogen Fluoride	0.00003	0.00003
Dew Point	-49°F	-50°F
Water	0.0009	0.0008

-100°F Dew Points are Typical

changes of the arced vapor; thus, the throughput requirement was four mass changes in the 12 minutes. In addition to the fast purge, it was required to provide a continuous slow purge capability up to shot time. This is designed to reduce the effects of continuous water and oil diffusion into the switches.

Pressure Control

The reprocessing system must supply vapor to the Marx switches, the laser-triggered rimfire switches, the Marx trigger generators, trigger amplifier, grounding relay, and laser trigger system. Each of these switches is designed to operate at a range of pressures. The reprocessing system is required to meet these various pressure ranges.

Cost Effectiveness

The requirement to produce vapor meeting commercial cylinder vapor specifications meant that the reprocessor system must be a cost-effective option to providing the machine with vapor from cylinders. PBFA-II is designed for a shot rate of one per day. The four mass changes of vapor per purge leads to over 2000 lbm of SF6 for a purge which translates to a cost of $8,000 per shot (purge). Therefore, cylinder vapor would cost approximately $2,000,000 per year. Typically, a system should pay for itself in 3 to 5 years to be considered cost-effective. This became the criteria in designing the system. The resulting system cost was approximately $1.25M making it very cost-effective.

Reprocessing System Description

The SF6 Reprocessing System schematic is presented as Fig. 2. This system can be separated into subsystems for more clear understanding of the processes involved.

- o Fast Purge
- o Slow Purge
- o Liquification
- o Vaporization
- o Vapor Phase Clean-Up
- o Pressure Control

Each of these subsystems will be briefly described, pointing out their primary use in the system.

Fast Purge Subsystem

Following a shot or a prefire, a high rate purge of all the circuits is used. This high rate is based on four throughputs of initially arced vapor in a 12-minute period. The high rate causes increased turbulence in the switch vapor space as well as reduces the cost of experiment time when the purge is required following a prefire. A large bank on nonlubricated, dual acting, reciprocating compressors pulls suction on the exhaust manifolds of all SF6 vapor circuits. The 375-scfm discharge is to a large vapor storage tank designed to accept four full-capacity purges before reaching its pressure limitation. Maximum pressure is selected to disallow liquification during low temperature weather conditions at SNL.

Slow Purge Subsystem

A low positive pressure has always been maintained in all SF6 insulated equipment at SNL when the surrounding liquids are in the tanks. With acceptance of the diffusion of water and oil through switch materials as an impossible-to-prevent means of contamination, a low rate continuous purge is introduced during low positive pressure conditions. In the case of the rimfire switches, in their surrounding water, should a saturated level of water vapor at low pressure be allowed to be reached, later pressurization to working pressures would cause supersaturation to occur and free water droplets (fog) within the switch would occur. The effects of such a condition are unknown; however, in the interelectrode gap, it could lead to variation of breakdown conditions, both triggered and self-break. Diffusion of water through the relatively thick sections of the switch housing requires extended periods before the moisture is available on the internal SF6 vapor side of the chamber wall. Therefore, time-in-service for various switches, without slow purge, could cause variations in moisture level between switches and upon repressurization, variations in the interelectrode gap. These variations could be a source of switch jitter. The effects discussed are not proven, but their possibility definitely exists and must await tests for final evaluation.

Liquification Subsystem

Following either Fast Purge or Slow Purge, the vapor is compressed to 350 psig in a bank of two-stage, nonlubricated, reciprocating compressors pulling suction directly from the SF6 manifolds and the vapor storage tank. The 100-scfm discharge is to a water-cooled desuperheating exchanger and then to the liquid storage vessel. A refrigerated liquid phase SF6 spray, over a packed section of tower, acts as the vapor condenser. Noncondensible gases are trapped in the upper head of the tank and are purged with a periodic venting system.

Noncondensible gas separation and large mass storage, 10,000 lbm, are primary design goals of the liquification subsystem. Most known arc products have boiling points below that of SF6 and will be in dissolved liquid phase when stored with SF6. Water and oil will both reach saturation in liquid SF6 with excess liquid separating as floating liquid layers on the dense SF6 liquid. A blowdown system is incorporated in the upper vessel area to allow removal of these liquids without shutting down the operation.

Liquid Phase Clean-Up

Saturated liquid pumps pull suction on the lower vessel, forwarding liquid SF6 to a dual column, molecular sieve dryer, then through three columns designed to remove the arc products dissolved in the liquid. Initial tower materials are CaO, NaOH, and Al_2O_3 pellets, stated to be successful materials for removal of these compounds. Sample testing will be used to

assure proper operation and later modifications of materials may be required.

Drying in liquid phase requires very low superficial flow rates through the molecular sieve columns and the exact level of moisture in the liquid phase discharge is not easily determined. A continuous recycle of liquid from the Liquid Phase Clean-Up Subsystem is sub-cooled using a refrigeration loop for reintroduction to the liquid storage vessel as the spray condenser.

<u>Vaporazation Subsystem</u>

SF6 has a relatively large latent heat of around 30 Btu/lbm, very similar to common refrigerants. An electrical vaporazation process is needed to produce the matching 375-scfm flow rate under Fast Purge. Dual, redundant 120-kW vaporizers are used to provide the necessary heat input.

<u>Vapor Phase Clean-Up Subsystem</u>

Oil vapor removal proceeds dual vapor phase dryers followed by filtration to prevent molecular sieve material being transported to the switch circuits. Drying the SF6 in vapor phase is much more well established and -100°F dew point or lower is expected, matching the quality of SF6 vapor from storage cylinders.

<u>Pressure Control Subsystem</u>

A complex system of flow switching and pressure regulation is designed to meet the Fast Purge, Slow Purge, and firing pressure accelerator requirements. Nonelectrical controls and instruments have been selected, as much as was possible, to improve the reliability of the system in PBFA-II. Large electrical transients during the shot are suspect as control failure mechanisms on previous accelerators.

<u>Conclusion</u>

The SF6 Reprocessing System, as described herein, is presently being constructed and will be started up in early 1986. A very small system designed around a commercial reclaimer, but incorporating the concepts given above, has recently been started and the -100°F dew point vapor has been achieved.

At present, sample testing is conceived as the only method of control on arc product removal and supplied vapor quality. This test program will be a major area of concern. The system may require subsequent modification to achieve design conditions or improve beyond present commercial SF6 quality.

The effects of vapor quality on the simultaneity of firings on parallel module pulse power accelerators is not clearly known at present.

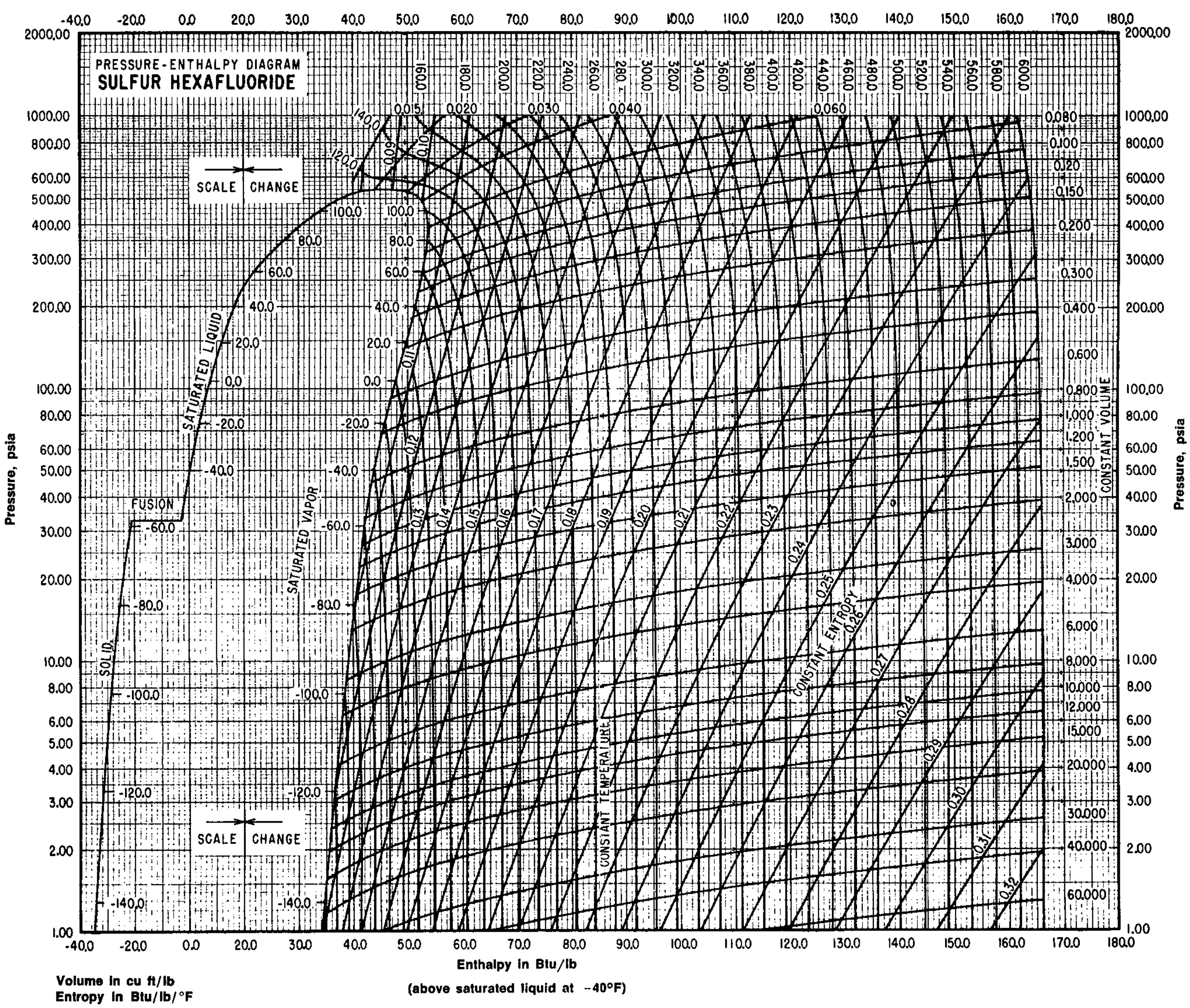

Fig. 1. SF6 Pressure Enthalpy Diagram

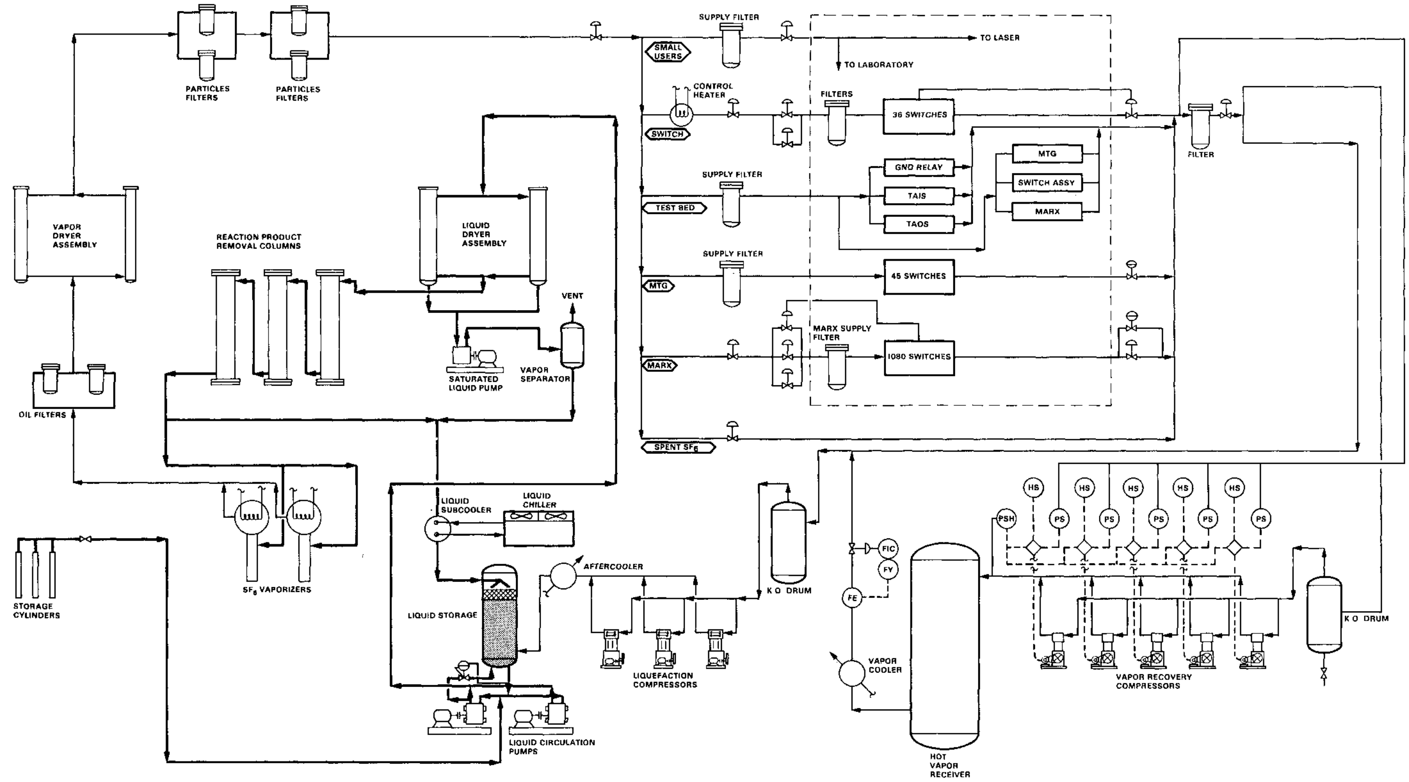

Fig. 2. SF_6 RECOVERY SYSTEM PROCESS FLOW SHEET